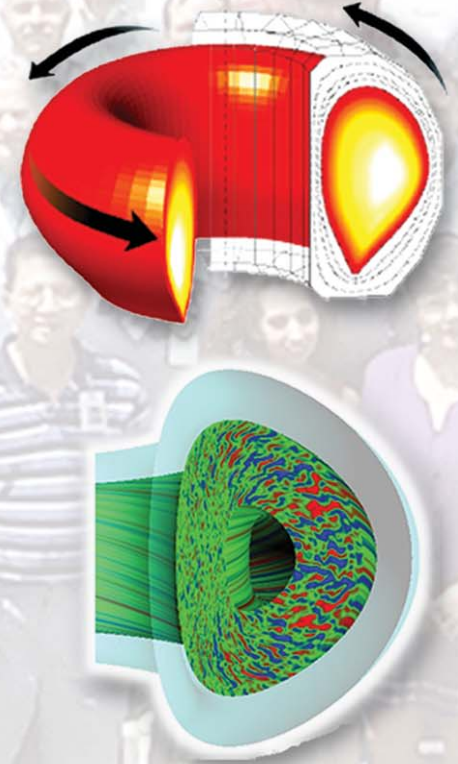


DIII-D National Fusion Program

by
T.S. Taylor

Presented at
Office of Fusion Energy Science
FY08 Budget Planning Meeting
Washington, DC

March 14–15, 2006



Outline of the DIII-D Presentations

- | | | |
|---|------------------------------|------------|
| • Introduction | T.S. Taylor (GA) | 15 minutes |
| • DIII-D Research Program Plans | M.R. Wade (ORNL) | 30 minutes |
| • University Research and DIII-D | W.W. Heidbrink
(Columbia) | 15 minutes |
| • DIII-D Program Budgets
and Schedules | R.D. Stambaugh (GA) | 15 minutes |
| • Discussion | | 10 minutes |

DIII-D is a Large, International Program



Active Collaborations 2004

US Labs

ANL (Argonne, IL)
LANL (Los Alamos, NM)
LBNL (Berkeley, CA)
LLNL (Livermore, CA)
ORNL (Oak Ridge, TN)
PPPL (Princeton, NJ)
SNL (Sandia, NM)

Industries

Calabasas Creek (CA)
CompX (Del Mar, CA)
CPI (Palo Alto, CA)
Digital Finetec (Ventura, CA)
DRS (Dallas, TX)
DTI (Bedford, MA)
FAR Tech (San Diego, CA)
IOS (Torrance, CA)
Lodestar (Boulder, CO)
SAIC (La Jolla, CA)
Spinner (Germany)
Tech-X (Boulder, CO)
Thermacore (Lancaster, PA)
Tomlab (Willow Creek, CA)
TSI Research (Solana Beach, CA)

US Universities

Auburn (Auburn, Alabama)
Colorado School of Mines (Golden, CO)
Columbia (New York, NY)
Georgia Tech (Atlanta, GA)
Hampton (Hampton, VA)
Lehigh (Bethlehem, PA)
Maryland (College Park, MD)
Mesa College (San Diego, CA)
MIT (Boston, MA)
Palomar (San Marcos, CA)
New York U. (New York, NY)
SDSU (San Diego, CA)
Texas (Austin, TX)
UCB (Berkeley, CA)
UCI (Irvine, CA)
UCLA (Los Angeles, CA)
UCSD (San Diego, CA)
U. New Mexico (Albuquerque, NM)
U. Rochester (NY)
U. Utah (Salt Lake City, UT)
Washington (Seattle, WA)
Wisconsin (Madison, WI)

Russia

Ioffe (St. Petersburg)
Keldysh (Udmurtia, Moscow)
Kurchatov (Moscow)
Moscow State (Moscow)
St. Petersburg State Poly (St. Petersburg)
Trinit (Troitsk)
Inst. of Applied Physics (Nizhny Novgorod)

European Community

Cadarache (St. Paul-lez, Durance, France)
Chalmers U. (Goteberg, Sweden)
CFN-IST (Lisbon, Portugal)
CIEMAT (Madrid, Spain)
Consorzio RFX (Padua, Italy)
Culham (Culham, Oxfordshire, England)
EFDA-NET (Garching, Germany)
Frascati (Frascati, Lazio, Italy)
FOM (Utrecht, The Netherlands)
Helsinki U. (Helsinki, Finland)
IFP-CNDR (Italy)
IPP (Garching, Greifswald, Germany)
ITER (Garching, Germany)
JET-EFDA (Oxfordshire, England)
KFA (Julich, Germany)
Kharkov IPT, (Ukraine)
Lausanne (Lausanne, Switzerland)
IPP (Greifswald, Germany)
RFX (Padova, Italy)
U. Dusseldorf (Germany)
U. Naples (Italy)
U. Padova (Italy)
U. Strathclyde (Glasgow, Scotland)

Japan

JAERI (Naka, Ibaraki-ken, Japan)
JT-60U
JFT-2M
Tsukuba University (Tsukuba, Japan)
NIFS (Toki, Gifu-ken, Japan)
LHD
Hiroshima University (Japan)

Other International

Australia National U. (Canberra, AU)
ASIPP (Hefei, China)
Dong Hau U. (Taiwan)
KBSI (Daegon, S. Korea)
KAERI (Daegon, S. Korea)
Nat. Nucl. Ctr. (Kurchatov City, Kazakhstan)
Pohang U. (S. Korea)
Seoul Nat. U. (S. Korea)
SWIP (Chengdu, China)
U. Alberta (Alberta, Canada)
U. of Kiel (Kiel, Germany)
U. Toronto (Toronto, Canada)

- 90 institutions participate
- 515 active users
 - 119 GA
 - 396 others
- 317 scientific authors (2004)
 - 577 cumulative
- 1082 visits to GA (2000–2004)
- Students and faculty have been from
 - 65 universities
 - 28 states

BROAD INTEREST IS SHOWN IN THE 586 RESEARCH PROPOSALS FOR CY06–07

FOREIGN

CEA Cadarache 6	FSZ Julich 7
EFDA-CSU 8	IPP Garching 7
ERM-KMS 1	JAERI 1
Euratom 2	U. Toronto 7
	UKAEA 11

Total: 50

DOMESTIC

Columbia 22	ORNL 21
FarTech 4	PPPL 66
Georgia Tech 2	SNL 7
GA 276	UCI 6
Lehigh 2	UCLA 30
LLNL 44	UCSD 30
MIT 3	U. Texas 4
ORISE 4	U. Wisconsin 15

Total: 536

DIII-D Program Recognition in FY05

- The Board of Directors of **Fusion Power Associates** presented its **2005 Leadership Award to Ronald D. Stambaugh** in recognition of his outstanding leadership qualities, his many important scientific contributions, outstanding leadership to the DIII-D program and guidance to the national fusion program, to improve the ultimate fusion product, an economic fusion power device.
- **Dr. Anthony Peebles** (UCLA) became a **Fellow of the American Physical Society** "For his leadership in developing the field of turbulence measurements in hot, magnetically confined plasmas."
- **Dr. Vincent S. Chan** (GA) became **Chair-elect of the Division of Plasma Physics** of the American Physical Society.
- **Dr. Steven L. Allen** (LLNL) is the **secretary-treasurer of the Division of Plasma Physics** of the American Physical Society.
- **Dr. Keith H. Burrell** became **Chair-elect of the Transport Task Force**.
- **General Atomics** received the first-ever **Science and Technology Education Programs (STEP) Corporate award** for its outstanding continued support of the programs offered through the STEP Conferences in Riverside and Hawaii.
- **Dr. Ronald D. Stambaugh** (GA) gave an **invited lecture** in Berlin on "Fusion Physics Toward ITER" at the **German Physical Society's 100th anniversary of Einstein's first papers**.
- **Dr. Robert L. La Haye** (GA) gave a **review presentation at the APS-DPP** meeting on "Review of Neoclassical Tearing Modes and Their Control," which highlighted many DIII-D experimental results.

Summary of Papers and High Visibility Presentations of The DIII-D and GA Theory Programs in FY05

- **Over 70 refereed publications**
 - 33 papers for the special issue of Fusion Science and Technology published
- **24 IAEA presentations**
- **8 APS-DPP invited presentations**
- **1 APS-DPP review presentation**
- **1 EPS post deadline presentation**
- **1 invited H-mode workshop invited paper**
- **2 RF conference invited papers**

The Long Torus Opening Has Provided DIII-D With Exciting Capabilities for the Future

— Made possible by an alternate operations schedule —

- Preserved run time capability
 - FY06 (12 weeks)
 - FY07 (25 weeks)
 - FY08 (25 weeks)

DIII-D Facility Schedules (05–08)

Activity Name	Fiscal Year 2005													Fiscal Year 2006													Fiscal Year 2007													Fiscal Year 2008																								
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S																
Schedule FY05-08	Operations													Cool down / Vent		Long Torus Opening													Close / Startup		Operations			Operations													Main		Operations															
	14 weeks																												12 weeks		Contingency			Main			12 weeks			Contingency					12 weeks			Contingency																
	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S																

- Anticipate completion of:
 - ECH- 6 long pulse gyrotrons
 - Rotation of 210 degree beamline to counter
 - Lower divertor modification
 - Cooling water tower replacement
 - MG refurbishment
 - TF belt bus cooling for 10 s ops (partially done)
 - Diagnostic upgrades and refurbishments

Operating Schedules FY07–08

PROPOSED DIII-D FY2007 OPERATIONS SCHEDULE																											
Oct 06							Nov 06							Dec 06							Jan 07						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
1	2	3	4	5	6	7							1	2							1	2					3
8	9	10	11	12	13	14	5	6	7	8	9	10	11	3	4	5	6	7	8	9	7	8	9	10	11	12	13
15	16	17	18	19	20	21	12	13	14	15	16	17	18	10	11	12	13	14	15	16	14	15	16	17	18	19	20
22	23	24	25	26	27	28	19	20	21	22	23	24	25	17	18	19	20	21	22	23	21	22	23	24	25	26	27
29	30	31					26	27	28	29	30			24	25	26	27	28	29	30	28	29	30	31			
														31													
Feb 07							Mar 07							Apr 07							May 07						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
					1	2	3						1	2	3	4	5	6	7								
4	5	6	7	8	9	10	4	5	6	7	8	9	10	8	9	10	11	12	13	14	6	7	8	9	10	11	12
11	H	13	14	15	16	17	11	12	13	14	15	16	17	15	16	17	18	19	20	21	13	14	15	16	17	18	19
18	19	20	21	22	23	24	18	19	20	21	22	23	24	22	23	24	25	26	27	28	20	21	22	23	24	25	26
25	26	27	28				25	26	27	28	29	30	31	29	30						27	H	29	30	31		
Jun 07							Jul 07							Aug 07							Sep 07						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
					1	2	1	2	3	H	5	6	7						1	2	3	4					1
3	4	5	6	7	8	9	8	9	10	11	12	13	14	5	6	7	8	9	10	11	2	3	4	5	6	7	8
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17	18	19	20	21	22	23	22	23	24	25	26	27	28	19	20	21	22	23	24	25	16	17	18	19	20	21	22
24	25	26	27	28	29	30	29	30	31					26	27	28	29	30	31		23	24	25	26	27	28	29
																					30						

Plasma Ops Optional Ops Vent Startup

PROPOSED DIII-D FY2008 OPERATIONS SCHEDULE																											
Oct 07							Nov 07							Dec 07							Jan 08						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
	1	2	3	4	5	6							1	2	3						1						
7	8	9	10	11	12	13	4	5	6	7	8	9	10	2	3	4	5	6	7	8	6	7	8	9	10	11	12
14	15	16	17	18	19	20	11	12	13	14	15	16	17	9	10	11	12	13	14	15	13	14	15	16	17	18	19
21	22	23	24	25	26	27	18	19	20	21	22	23	24	16	17	18	19	20	21	22	20	21	22	23	24	25	26
28	29	30	31				25	26	27	28	29	30		23	24	25	26	27	28	29	27	28	29	30	31		
														30	31												
Feb 08							Mar 08							Apr 08							May 08						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
					1	2							1						1	2	3	4	5				
3	4	5	6	7	8	9	2	3	4	5	6	7	8	6	7	8	9	10	11	12	4	5	6	7	8	9	10
10	H	12	13	14	15	16	9	10	11	12	13	14	15	13	14	15	16	17	18	19	11	12	13	14	15	16	17
17	18	19	20	21	22	23	16	17	18	19	20	21	22	20	21	22	23	24	25	26	18	19	20	21	22	23	24
24	25	26	27	28	29		23	24	25	26	27	28	29	27	28	29	30				25	H	27	28	29	30	31
							30	31																			
Jun 08							Jul 08							Aug 08							Sep 08						
S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S	S	M	T	W	T	F	S
1	2	3	4	5	6	7							1	2	3	H	5				1	2					
8	9	10	11	12	13	14	6	7	8	9	10	11	12	3	4	5	6	7	8	9	7	8	9	10	11	12	13
15	16	17	18	19	20	21	13	14	15	16	17	18	19	10	11	12	13	14	15	16	14	15	16	17	18	19	20
22	23	24	25	26	27	28	20	21	22	23	24	25	26	17	18	19	20	21	22	23	21	22	23	24	25	26	27
29	30						27	28	29	30	31			24	25	26	27	28	29	30	28	29	30				
														31													

Plasma Ops Optional Ops Vent Startup

DIII-D Status

- **210 Neutral beam rotation**
 - Neutral beam rotation task completed
 - Beamlines (30, 330) to start March 27
 - Beamlines (210, 150) to start April 4
- **New high triangularity divertor**
 - Divertor plate installed
 - Graphite tiles installed
- **Two new cooling towers**
 - Cooling tower operation to start March 11
- **Electron cyclotron system**
 - 4 new gyrotron stands modified or built
 - One new CPI gyrotron P4 installed
 - CPI depressed collector gyrotron installed
 - 4 gyrotrons ready for operations in May
- **Diagnostics**
 - In vessel calibration completed by March 24
- **DIII-D vessel**
 - Closed and pumped down March 3 for first leak check
 - Opened March 9 to complete tile installation and diagnostic calibrations
 - Final pump down scheduled March 24
- **Operations**
 - Plasma conditioning (tokamak discharges with beams) is scheduled to start April 24
 - Plasma physics operation is scheduled to start in May

Installation of New Cooling Towers



Co Plus Counter NBI will Provide Unique Capability in the US Fusion Program

PROVIDES

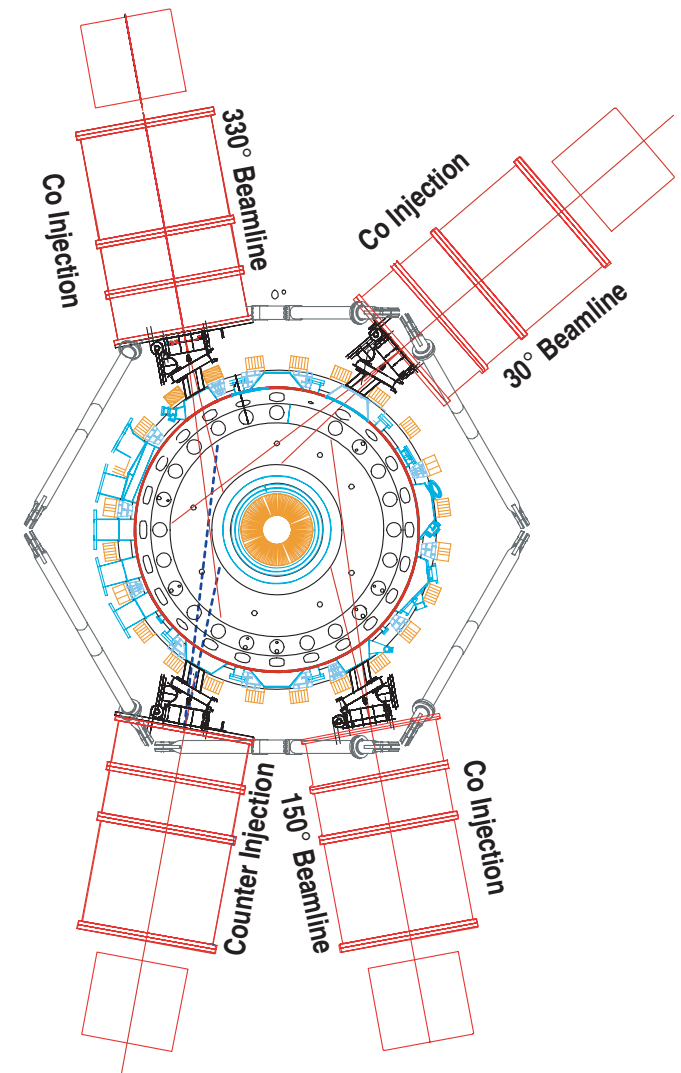
- Plasma heating
- Current drive and current profile control
- Rotation control

ENABLES

- QH-mode with central co-rotation
- Physics of rotation
- RWM stability at low rotation
- NTM stabilization with modulated rf
- Fast ion distribution control
- Full bootstrap discharges
- Physics of NBCD
- Transport barrier control (ExB and Shafranov shift)

DIAGNOSTICS

- Co plus counter viewing MSE, $J(\rho)$ and E_r with high resolution
- Co plus counter CER, improved poloidal and toroidal rotation

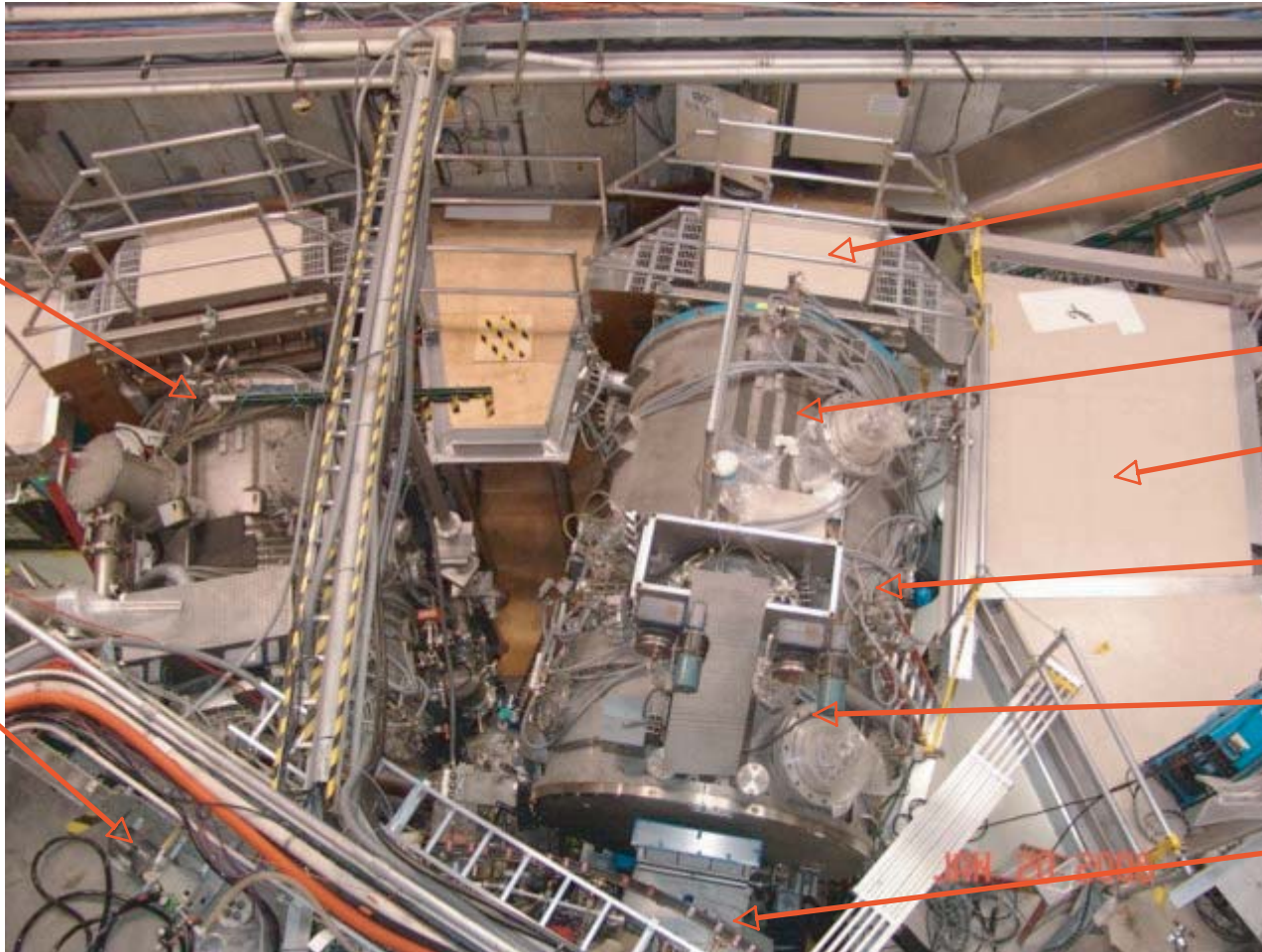


DOE Joule Milestone

Installation of Rotated 210 Beamline

150
Beamline

DIII-D



Walkway
over Ion
Source
Housing

Spool #1

Ten-Foot
Platform

Spool #2

Spool #3

Drift-Duct

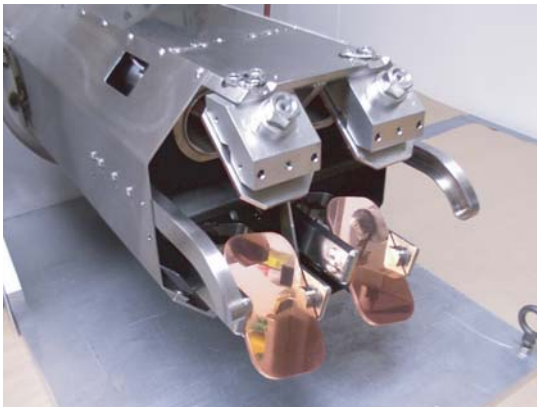
The DIII-D EC System will Provide Enhanced Off-axis Current Profile Control and Important Physics Capability



First replacement gyrotron installed in refurbished "socket" and started up

Refurbished "socket" for second replacement gyrotron in background

Steerable Launcher (PPPL)



Developmental depressed collector gyrotron installed in new "socket"

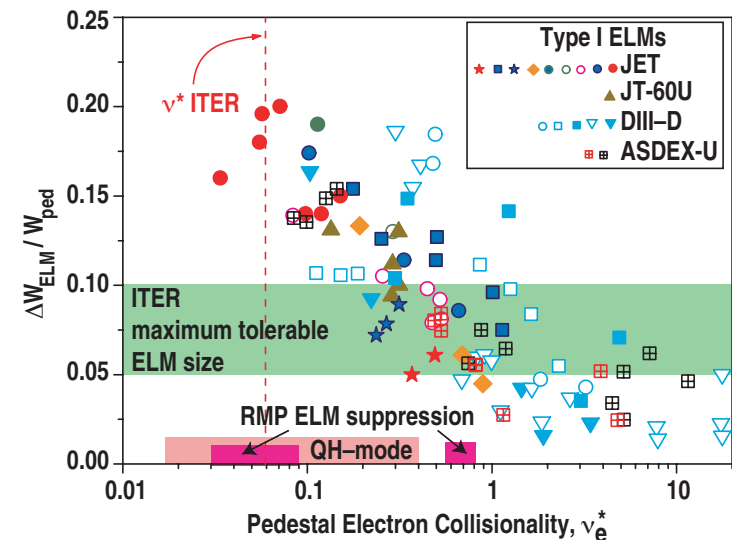
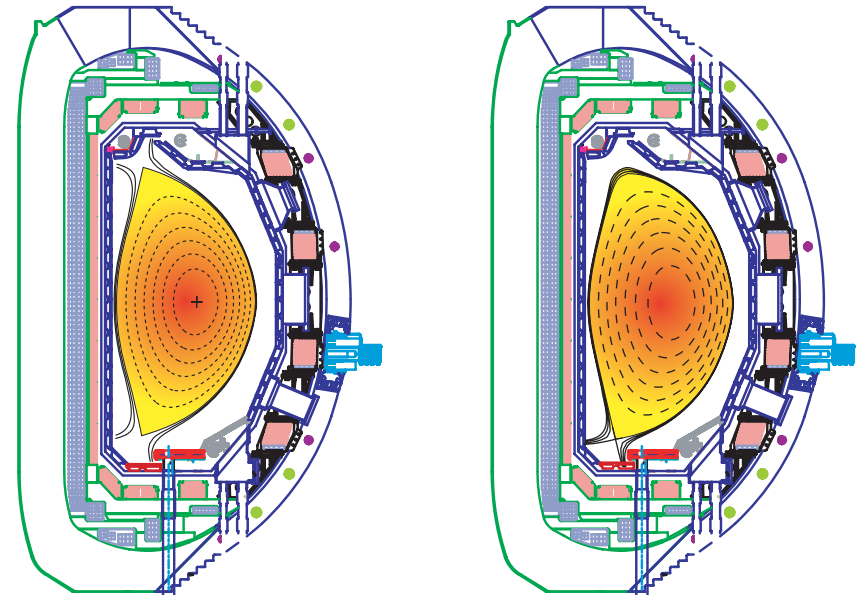
- **Physics Enabled**

- Current drive
- Current profile control
- MHD stabilization
- Electron heating
- Transport science
- Transport barriers

The Divertor Modification will Provide Density Control in ITER Shaped SND and DND

PHYSICS ENABLED:

- Improved density control in $A7DN$ plasmas
- Transport and stability over range of v^* (n_e)
- Pedestal physics with range of v^* , SND and DND
- Plasma flow and impurity retention in the plasma boundary
- Attachment/detachment control



New Lower Divertor Shelf Installation

Divertor shelf manufactured at ASIPP



Significant New Measurement Capability Will Be Available Following the LTOA

New Capability

MSE, counter viewing (LLNL)
CER, counter viewing (PPPL)
BES, additional high-sensitivity channels (Wisc.)
 D_{α} , Mod B (UCSD)
SXR poloidal array
MDS, under shelf spectral views
MIMES (midplane) (UCSD)
QMBs (Wisc., Julich)
Shelf halo current monitors
Contoured center post tiles

Improved Capability

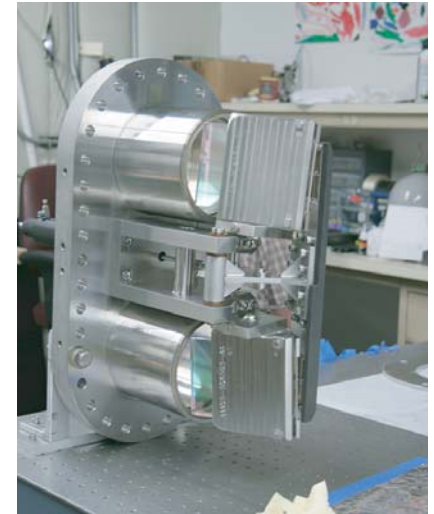
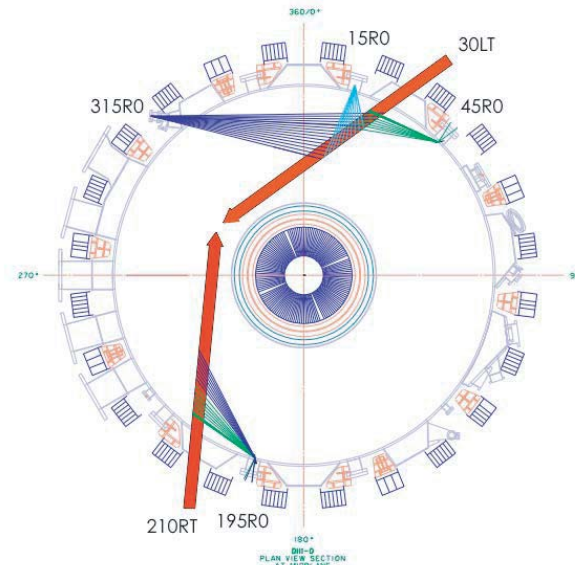
FIR Scattering (UCLA)
ECE Radiometer (UT, UM)
Langmuir Probes-floor (SNL)
Recycling camera (LLNL)
Filterscope views (ORNL)
Lithium beam
Fast framing camera (UCSD)
Divertor Thomson scattering
Reflectometer (UCLA)
Interferometer (ORISE)

- DIAGNOSTICS: Clear example of DIII-D team effort with significant effort and contributions from collaborating institutions

Beam Rotation Provides Opportunity for New and Upgraded diagnostic systems

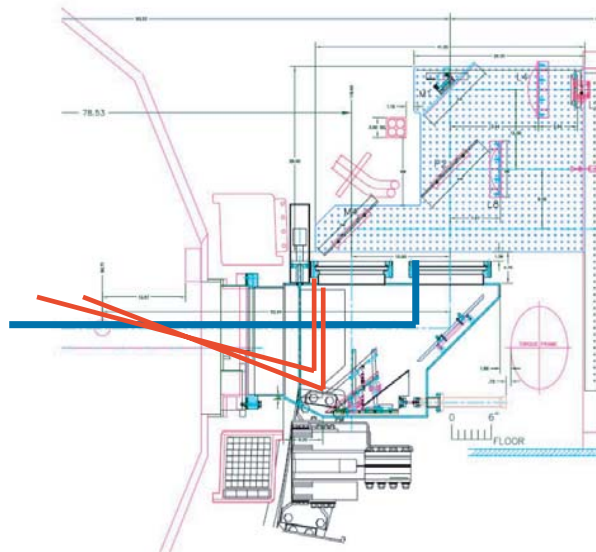
MSE (LLNL)

- 24 new chords
- E_r , J independently
- improved resolution



FIR (UCLA)

- $0\sim 1\text{ cm}^{-1}$
- $5\sim 15\text{ cm}^{-1}$
- Adjustable k and location

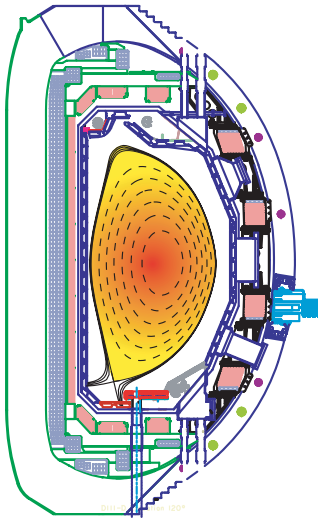


DIII-D PAC Comments on the LTOA

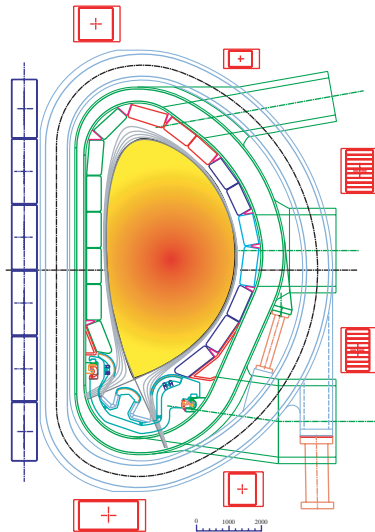
- “The PAC was pleased to find the LTOA on schedule and commends the entire DIII-D team for an outstanding effort in accomplishing this feat”
- “The DIII-D team has clearly followed the guidance from last year’s PAC to not neglect diagnostic capability during the LTOA. . . The team responded to almost all of the recommendations concerning diagnostics in last year’s report.”
- “When operation resumes DIII-D will not only have an impressive new set of operational capabilities, but also an excellent set of diagnostics with which to unravel the new physics”
- “The new capabilities, together with an unparalleled diagnostic set and highly competent team guarantee that DIII-D will continue in its position at the forefront of the world’s fusion research program”

Research on DIII-D Will Significantly Advance the Research Program on ITER

DIII-D
 $\delta_{x-pt} = 0.63$



ITER
 $\delta_{x-pt} = 0.58-0.68$



- **Unparalleled operating flexibility allows strong contribution to ITER's scientific needs**
 - Predictive understanding of key physics issues
 - Physics basis for key remaining design decisions
 - Validation of integrated scenarios
 - Development of high-performance steady-state operation
- **Strong international cooperation maximizes the benefits to ITER**
 - Wide international participation in DIII-D experiments
 - ITPA leadership, joint experiments
- **DIII-D research provides for future excellence of ITER's fusion science**
 - Opportunities for young researchers
 - Train staff for ITER operation

DIII-D Research Program Consists of Research Thrusts and Enduring Topical Science Areas

2006 and 2007 Research Thrusts and Leaders

	AT-1 Advanced Scenario Development	IT-1 ELM Control for ITER	IT-2 ITER Hybrid Scenario	IT-3 NTM Control for ITER	IT-4 RWM Control for ITER	SC-1 Pedestal Width Physics
Topical Area Manager	T. Luce C. Greenfield	M. Fenstermacher T. Jernigan	C. Petty J. Jayakumar	R. La Haye D. Humphreys	A. Garofalo M. Okabayashi	A. Leonard G. Staebler R. Groebner
Stability physics E. Strait	✓	✓	✓	✓	✓	✓
Confinement, transport physics K. Burrell	✓	✓	✓			✓
Boundary physics S. Allen	✓	✓	✓			✓
Heating and current drive physics R. Prater	✓		✓	✓		✓

Table shows areas of strong overlap

- Program leadership reflects the national character of the DIII-D Program
- Topical science areas provide broad scientific base
- Research thrusts are focussed on ITER research needs

Broad Community Participation is a Significant Contributor to the Scientific Excellence of the DIII-D Program

— Proposals received for 2006 – 2007 experiment campaign —

U.S.		International	
Columbia University	22	CEA Cadarache	6
FarTech	4	EFDA-CSU	8
Georgia Tech	2	ERM-KMS	1
General Atomics	276	Euratom	2
Lehigh University	2	FSZ Julich	7
LLNL	44	IPP Garching	7
MIT	3	JAEA	1
ORISE	4	Univ. Toronto	7
ORNL	21	UKAEA	11
PPPL	66		50
SNL	7		
UC Irvine	6	From Int'l Labs	43
UCLA	30	From Universities	125
UCSD	30	From Nat'l Labs	138
Univ. Texas	4	From Industry	280
Univ. Wisconsin	15		
	536	Total	586

Significant Progress will be Made in FY06–08, But a Large Backlog of Experiments Will Remain

Area	Proposals Received	Unique Proposals	Proposals in 12 week plan for 2006	Proposals in 12 week plan for 2007	Proposals in 12 week plan for 2008	Backlog of Proposals Post 2008
Stability	70	64	5	5	4	50
Confinement	93	83	7	6	4	68
Heating and Current Drive	50	40	1	6	6	27
Boundary	60	60	5	5	4	46
Advanced Scenarios	59	37	4	6	7	20
ITER Hybrid Scenarios	47	37	5	5	5	23
Pedestal Width Physics	29	22	1	3	3.5	14.5
RWM Control for ITER	56	40	9	5	6	20
NTM Control for ITER	13	7	3.5	2.5	1	0
ELM Control for ITER	109	94	6	5	5	78
Total Proposals	586	484	46.5	47.5	45.5	348.5

DIII-D PAC Comments on the DIII-D Program Plan

- The experimental program presented to the PAC “emphasized ITER support . . . the PAC agrees that this program element should receive the highest priority”
- “The plan emphasizes those areas of research in which DIII-D is uniquely well-suited to provide information critically needed to resolve near term design issues for ITER”
- “The PAC further notes that Advanced Tokamak regimes are highly relevant for ITER’s goal of extended burn, and advances in fusion science will be important in maximizing the return on the U.S. and world’s investment in ITER”